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Abstract

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DETERMINATION OF THE DIMENSIONS OF THE SUBSOLAR MAGNETOSPHERE FROM DATA OF GROUND-BASED OBSERVATIONS OF GEOMAGNETIC MICROPULSATIONS

(Presented by Academician A. N. Tikhonov on January 30, 1968)

One of the promising directions in the study of micropulsations is the investigation of the possibility of using them for diagnosing the parameters of the magnetosphere and the solar wind. Since at present only the general principles of the physical interpretation of micropulsations have emerged, along with the theoretical approach to the diagnostic problem ([2]), various empirical and semi-empirical methods ([1,3]) are widely used.

Among the variety of geomagnetic micropulsations, oscillations of type Pc 2–4, with periods T = 10–150 sec, are distinguished; they are observed almost continuously on the surface of the Earth facing the Sun. According to current ideas, these are natural hydromagnetic oscillations of the magnetosphere, excited at its periphery by solar corpuscular streams. The period of the oscillations naturally depends on the dimensions of the resonator, whose "walls" are the surface of the Earth and the shock-wave front that arises when the magnetosphere is streamlined by the solar wind and that bounds the geomagnetic field on the subsolar side, on average at a distance of ten Earth radii.

Direct measurements of the magnetic field and particle fluxes on satellites and rockets show that the boundary of the magnetosphere is in constant motion, approaching the surface of the Earth when the solar wind intensifies and receding when the wind weakens and the normal pressure on the surface of the magnetosphere decreases. Correspondingly, the periods of Pc 2–4 micropulsations also change. Thus, micropulsations of this type may be regarded as a simple ground-based indicator that makes it possible to monitor continuously the position of the magnetospheric boundary.

If the dependence of the period T of micropulsations on the dimensions of the magnetosphere along the Earth–Sun line is represented in the form $T = \mathrm{const} \cdot R^{\nu}$, then the main task will be the determination of the exponent ν. The proportionality coefficient is estimated from the condition that mean magnetospheric dimensions $R_0 \approx 10$ (in units of the Earth' s radius) correspond to typical periods $T_0 \approx 30$ sec. Thus,

$$T = T_0(R/R_0)^{\nu}, \tag{1}$$

where T_0 and R_0 are assumed to be known, and ν is the quantity to be determined.

In work ([1]), the exponent $\nu \sim 4.8$ was found by direct comparisons of satellite data on magnetospheric dimensions with the periods of Pc 2–4 micropulsations. In the present work an attempt is made to determine ν exclusively from ground-based data. For this purpose we use the case of an abrupt change in the period of Pc 2–4 micropulsations during sudden deformations of the magnetosphere arising under the action of inhomogeneities of the solar wind. During sudden compression (expansion) of the magnetosphere, the surface currents flowing along its boundary are intensified

(decrease), and a positive (negative) impulse of the magnetic field Si is observed at the Earth' s surface (Fig. 1a). It is interesting to note that sometimes, following a negative impulse, the micropulsations disappear completely (Fig. 1b, c).

The method for estimating the exponent ν is based on comparing the magnitude ΔB of the sudden impulse with the periods of the micropulsations T and T', observed before and after the sudden impulse.

According to Mead [4], the magnitude of the sudden impulse Si, recorded at the equator, is related in the following way to the dimensions of the magnetosphere R and R' before and after Si*:

$$\Delta B = \frac{B_1}{R^3}\left[\left(\frac{R}{R'}\right)^3 - 1\right], \tag{2}$$

where $B_1 = 25\,000\ \gamma$ ($1\ \gamma = 10^{-5}$ gauss). Eliminating the quantities R and R' from (2) by means of (1), we find

$$\lg\left(\frac{T}{T'}\right) =$$

$$= \frac{\nu}{3}\lg\left[1 + R_0^3\frac{\Delta B}{B_1}\left(\frac{T}{T_0}\right)^{3/\nu}\right]. \tag{3}$$

This formula makes it possible, from the set of experimental data on T, T', and ΔB, to determine the exponent ν. The results of preliminary measurements in 20 cases of changes in the period of micropulsations during Si lead to the value

Figure 1

Figure 1: Figure 1

$\nu \approx 4.6$. This is very close to the value found by direct comparisons between T and R.

Fig. 1. Examples of records of micropulsations. **a** –from top to bottom: Borok station ($\Phi = 52°,\ \Lambda = 123°20'$), Petropavlovsk ($\Phi' = 44°24',\ \Lambda = 218°14'$), Soroa –Cuba ($\Phi = 33°,\ \Lambda = 345°$) –2 VIII 1964; **b** –from top to bottom: Borok, Petropavlovsk, Soroa (Cuba), Dallas (USA) –2 V 1965; **c** –Borok station –14 XII 1958.

It is interesting to note that, for known ν, it is possible to determine the dimensions of the magnetosphere before and after Si with an accuracy not dependent on the accuracy of choosing the parameters R_0 and T_0. In fact, eliminating (R'/R) from (2) by means of (1), we obtain

$$R = 10\{[(T/T')^{3/\nu} - 1](25/\Delta B_\nu)\}^{1/3}. \tag{4}$$

A completely analogous form is taken by the formula for determining R'. Figure 2 shows the results of the corresponding measurements for $\nu = 4.6$.

A specific feature of the measurements described is that the change in the periods of the micropulsations was analyzed over a network of observatories located around the perimeter of the terrestrial globe, such as, for example, Borok, Petropavlovsk-on-Kamchatka (USSR), Soroa (Cuba), and in special experiments conducted at antipodal points (Borok, Hight, Dallas).

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* It should, however, be noted that, when observing at the Earth' s surface, the magnitude of Si will be somewhat higher as a consequence of the induction effect in the Earth' s crust. As is known, this effect is approximately taken into account by multiplying the measured values of Si by the coefficient 2/3.

The value of ν will be refined by both methods. Therefore let us note that formula (3), rewritten in the form

$$B_1 = R_0^3 \Delta B (T/T_0)^{3/\nu} \left[(T/T')^{3/\nu} - 1\right]^{-1}, \tag{5}$$

can be used for the experimental determination of B_1.

The boundary of the magnetosphere is formed under the action of solar corpuscular streams filling interplanetary space. Therefore data on the position and displacements of the boundary contain indirect information on the properties of the interplanetary medium in the vicinity of the Earth.

Fig. 2 and Fig. 3

Figure 2: Fig. 2 and Fig. 3

Fig. 2. Dependence of the period of Pc 2–4 type micropulsations on the dimensions of the magnetosphere

Fig. 3. Dependence of the period of micropulsations and the impulse magnitude ΔB on the dimensions of the magnetosphere and the solar-wind velocity (upper curve for compression of the magnetosphere, lower curve for expansion)

If one uses the relation $R = 1.068\,(M^2/4\pi m_p N V^2)^{1/6}$, which relates the dimensions of the magnetosphere to the pressure of the solar wind on the magnetosphere at the subsolar point [4], then, taking (1) into account, we obtain:

$$V = \frac{M}{R_0^3\sqrt{4\pi N m_p}}\left(\frac{T_0}{T}\right)^{3/\nu}. \tag{6}$$

Here M is the magnetic moment of the Earth, m_p is the proton mass, V is the wind velocity, and N is the proton concentration. Use of formula (6) for estimating the wind velocity from data on micropulsation periods is difficult because of the variability of the particle concentration in the interplanetary medium. If, however, it is assumed that $NV = \text{const}$ [5], then $V = \text{const}\,T^{-6/\nu}$. The value $\nu = 4.6$ was determined above, and the proportionality coefficient can be estimated from the condition that a mean wind velocity $V \approx 500$ km/sec corresponds to a typical period $T_0 \approx 30$ sec. Under these assumptions, the values of the solar-wind velocity corresponding to different periods of stable micropulsations were calculated (Table 1). The results of the calculation should, of course, be regarded as preliminary. In the future, direct comparisons of data on the parameters of corpuscular streams–

Table 1

T, sec	R	V, km/sec	T, sec	R	V, km/sec
10	7.9	2100	40	10.7	350
15	8.6	1250	45	10.9	300
20	9.2	880	50	11.2	250
25	9.6	650	55	11.5	230
30	10.0	500	60	11.7	210
35	10.2	420	65	11.9	185
			70	12.0	170

···with the observed periods of micropulsations will make it possible to refine the character of the relation between T and V.

Above we mentioned cases of a sudden cessation of micropulsations after negative Si (Fig. 1b). In Fig. 3 (lower curve), the vertical axis gives the magnitudes of the negative impulses, and the horizontal axis gives the corresponding magnetosphere dimensions R before Si, calculated from formula (1) for $v = 4.6$. The value R' cannot be estimated in the same way, since after the negative Si considered the oscillations cease. Since, however, R and ΔB are known, R' can be found from formula (2). It is interesting to note that in all cases of cessation of micropulsations the boundary of the magnetosphere after Si receded to considerable distances, $R' \approx$ 13-15. If the relation $V \approx 1/T^{6/v}$, derived under the condition $NV =$ const, is valid, this will lead to very small values of the wind velocity: $V \approx 150$ km/sec. It is possible, however, that the cessation of micropulsations occurs with a sharp drop both in the wind velocity and in the particle concentration*.

The upper curve of Fig. 3 shows the dependence between R and the magnitude ΔB of positive impulses. In the general case this dependence is not single-valued. Therefore, in selecting the cases shown in the graph, an additional relation of the form $T = 2T'$ was imposed.

Thus, a joint analysis of micropulsations over a wide range of periods and of sudden impulses of the magnetic field at the equator sharply increases the information content of ground-based observations of geomagnetic effects.

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* In addition, in this case we do not take into account the influence of the orientation of the interplanetary field on the excitation of Pc.

Note: Figure translations are in progress. See original paper for figures.